Auto-adaptive and faster algorithm to optimize the calculus of the current flows in radiating structures

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AUTO-ADAPTIVE AND FAST ALGORITHM TO OPTIMIZE THE CALCULUS OF THE CURRENT FLOWS IN RADIATING STRUCTURES

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Abstract

Accurate electromagnetic modeling is often too time-consuming. Solving electromagnetic scattering and radiation problems with moment methods or finite-element methods over a large frequency band requires the computer code to be run for every frequency sample. This is too expensive. So we propose a fast auto-adaptive method to optimize the calculus of the current flows for various radiating structures.

Introduction

The cost of computational electromagnetic simulation by the moment method or the finite-element method is expensive because the computer model has to be run for every frequency sample. But in recent years various interpolation algorithms have been developed and published [1-3]. Our aim is to obtain the current flows at the antenna surface over the frequency band using only a limited number of frequency samples, adding specific information based on the knowledge of the derivatives of these current flows [4-6]. Thus we have developed an original adaptive algorithm for which we present various results and comments for some structures.

Modeling

We propose an original method taking into account the formal knowledge of the derivatives of the variational expressions of the current flows. The numerical solution is obtained by a surface finite-element method coupled with an adaptive interpolation algorithm [5-6]. This approach takes into account the true electromagnetic behavior. From the frequency derivability results associated with the Huyghens principle for C^2 surfaces we obtain the two derivatives of the Rumsey reaction [4] by a computer algebra system (Maple), and we then compute the unknown current flows and their derivatives at the antenna surface for a very small number of frequency samples. The expressions of the derivatives of the current flow become more complex when the order of derivation increases, and although the kernel singularity is never stronger than the original, integration of the successive kernels needs specific developments.

To solve the Rumsey reaction numerically we use a finite-element computer code (SR3D by France Télécom R&D). This is based on an integral equation formulation with triangular finite-element discretization. Thus the SR3D software solves an equation of bilinear form where the current flow **X** is the unknown. Therefore the derivatives of flows of current (**X', X''**) are also solutions of a linear system of the form: A . **X** = B. Operator A remains the same, only the second member changes: B' for **X'** and B'' for **X''**. The operator consists of the successive derivatives of A and B and of lower-order derivatives of the current flow. Once the successive derivatives of the unknown current flows are computed at some sampling points over the frequency band, our special adaptive interpolation routine is applied to evaluate them.

Interpolation

Interpolating and approximating a function by polynomials or rational functions appears difficult if only a small number of sample points are known, without other information.

Many kinds of interpolation methods exist [1-3,7-14], for example the well known least-square method, the Taylor series, the Newton, Lagrange, Chebyshev and trigonometric polynomial interpolations, the piecewise polynomial functions, the Padé and the Chebyshev or Chebyshev-Padé approximations, the Thiele interpolation, the spline functions, and so on. Rational approximations are sometimes superior to polynomials because of their ability to model functions with poles. It is quite difficult to determine the degree of the two polynomials. The interpolation by rational functions seems more stable, however when the known points of the signal are widely spaced oscillations also appear. This approximation is sometimes used by Computer-Aided-Design software analyzing general planar structures (Model Based Parameter Estimation (MBPE) or Adaptive Frequency Sampling modules). It allows the number of computed points to be divided by two or more. Other methods can be used in signal processing (basis functions, wavelet functions, etc.).

So we have developed an original and flexible adaptive fifth-order polynomial interpolation based on the knowledge of the derivatives of the current flows. This choice allows the number of frequency samples to be still further reduced (figure 1). In this flow chart we present our adaptive algorithm based on the detection of a "pathology" in the behavior of the function. It is based on the variations of the first and second derivative functions. An auto-adaptive algorithm to automatically identify new sampling points is exposed here. The new frequency points are related to the variations of a real function of the frequency, $\Psi_M(f)$ defined from the M highest values of the current flows (about 10% of the number of degrees of freedom). Thus this method clearly improves the localization of the concentrations of fields so as to detect the emergence of new resonances with variation of the frequency.

Our model gives better results than other methods such as simple polynomial interpolation, spline functions, or least square [5-6]. When there is only one peak in the original function the Thiele interpolation gives very good results. Comparisons are obtained between various interpolation results and our adaptive model with 7 points only for a 30% bandwidth. In the case of two or more peaks when the sample frequencies are equally spaced, Maple's formula for the Thiele approximation has singularities which cause it to fail. Some solutions exist but they do not always agree. We present a comparison between various interpolation results and our model with 7 points only for a 40% bandwidth (figure 2). We observe an excellent agreement between our original test function and the theoretical results.

Results

We consider a circular waveguide over the frequency band 4.6-6 GHz. This structure is meshed with 4,432 elements at 5 GHz. Using finite-element SR3D code and 70 frequency points we compute the reference variations of the VSWR (Voltage Standing Wave Ratio) over this band, given by a green curve. Figure 3 shows the comparison between this green reference curve calculated from the classical computed current flows and the interpolated variations of the VSWR obtained from the classical computed current flows (red curve). This is level 0 of the algorithm. The quadratic error is less than 5%. However we have "pathological" behavior around 4.9 GHz. So we run the adaptive version of our modified SR3D code to refine the data set around this frequency: this is level 1 of the algorithm. Figure 4 presents the refined VSWR obtained by adding one point to the uniform frequency set. We observe an excellent agreement between the reference and the new interpolated VSWR.

In the case of a line-slotted patch antenna the reference results of SR3D code are obtained with 55 frequency points. In figure 5 we present some examples of the efficiency of the adaptive algorithm. Part (a) presents the comparison of the average of the twenty highest values of the modulus of current flow versus frequency (4.5-6.0 GHz) for various numerical simulations. Part (b) concerns the quadratic average of the twenty highest values of the current flows. It is sufficient to give a excellent idea of the behavior of the real current flow. When we implement the first level of our adaptive algorithm we observe a very good alignment between the optimized curve (red curve) and the reference points (green circles). If the second level of the algorithm is applied, an excellent agreement is obtained (green curve).

Conclusion

We have presented an original and auto-adaptive optimization technique to calculate current flow at the antenna surface over a large frequency band with a very small number of frequency samples. Knowing the formal derivatives of the current flow, we are able to compute an accurate polynomial interpolation to obtain this current flow at the surface of the antenna. Comparing our results and those obtained by other techniques we observe an excellent agreement and a significant reduction in computing time (about 90%).

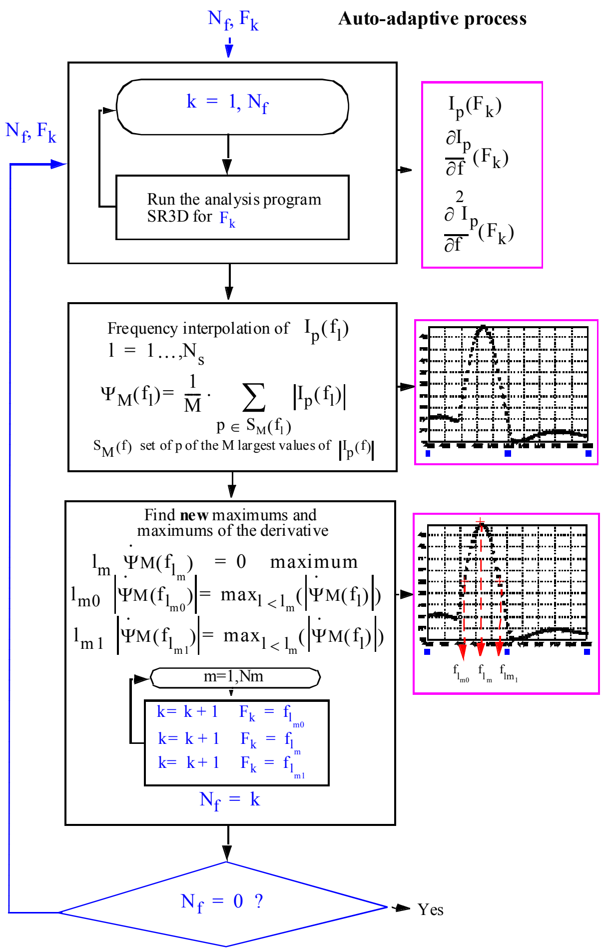


Figure 1 : Flow chart of the adaptive algorithm

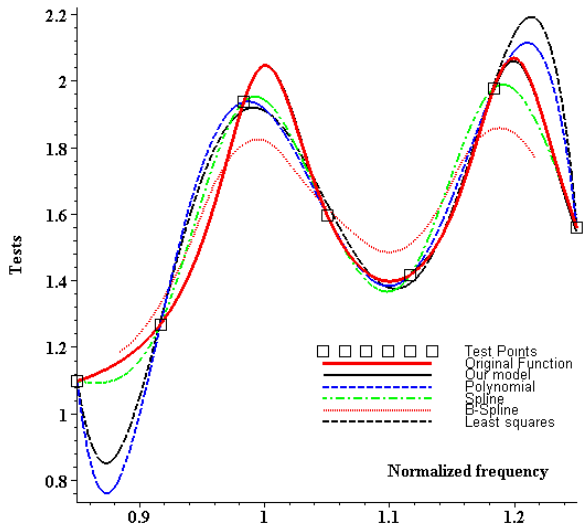


Figure 2 : Comparison between various interpolation results and our model with 7 points only for a 40% bandwidth. Here a fifth-degree polynomial is used in the least-square method.

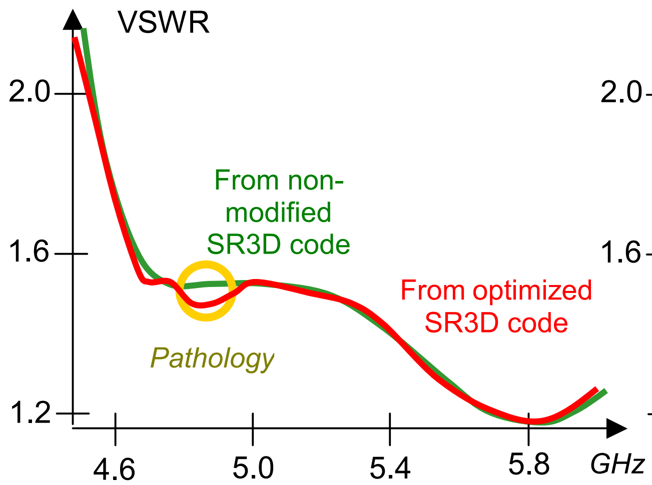


Figure 3 : Variations of the VSWR - Level 0
Interpolation code (red curve).
Comparison with the reference (green curve).

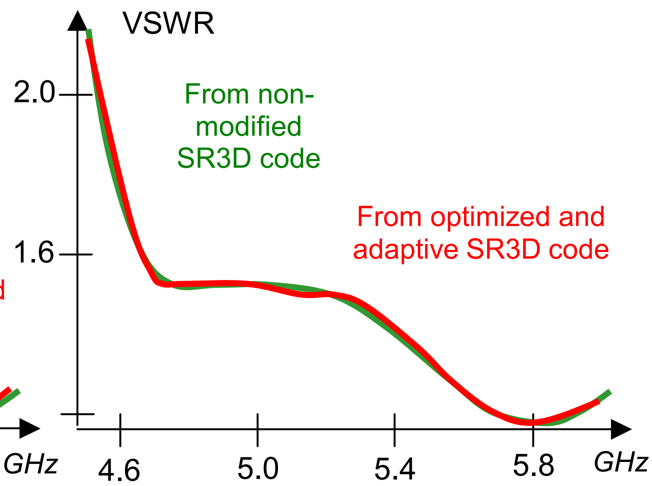
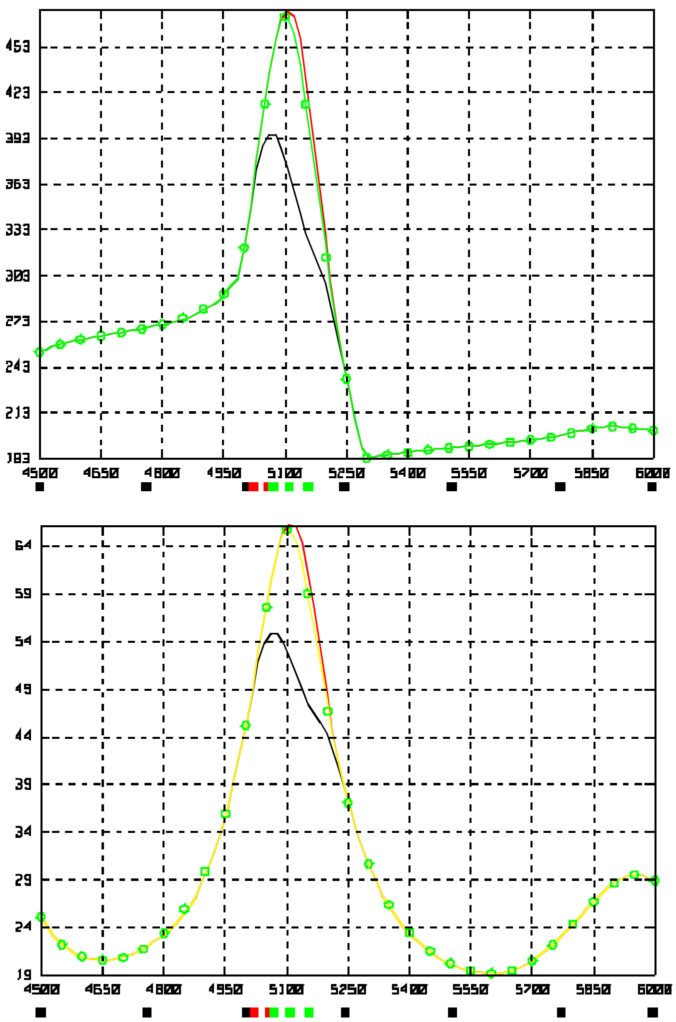


Figure 4 : Variations of the VSWR - Level 1
Adaptive interpolation code (red curve).
Comparison with the reference (green curve).



(a)

(b)

Black curve : Numerical simulation including interpolation with 7 frequency samples only.

Red curve : Simulation with first level of refinement (2 additional points found by the adaptive algorithm)

Green curve : Second level of refinement (3 new additional points found by the adaptive algorithm)

O : Values calculated by the classical SR3D code without any optimization

Figure 5 :
(a) Comparison of the average of the twenty highest values of the current flows

(b) Comparison of the quadratic average of the 20 highest values of the current flows

versus frequency (4.5 - 6.0 GHz) for various numerical simulations.

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